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(54) **CONTROL APPARATUS FOR INTERNAL COMBUSTION ENGINE**

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(2), (4) Date: **May 8, 2013**

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(57) **ABSTRACT**

An object of this invention is to accurately detect a sensitivity abnormality of an in-cylinder pressure sensor over a wide operating range without using other sensor outputs or the like. Based on only the output of an in-cylinder pressure sensor **44**, an ECU **50** acquires a first parameter that is affected by an output sensitivity of the sensor, and a second parameter that is not affected by the output sensitivity. Specifically, the ECU **50** acquires a heat release quantity PV^* as the first parameter, and acquires an indicated torque ratio ($A2/A1$) as a second parameter. The ECU **50** also calculates a determination coefficient α that is a ratio between the first and second parameters, and determines that the output sensitivity of the in-cylinder pressure sensor **44** is abnormal when the determination coefficient α deviates from an allowable range. Thus, even without utilizing another sensor output or the like in an auxiliary manner or previously preparing a large amount of data or the like, a sensitivity abnormality of the in-cylinder pressure sensor **44** can be easily detected over a wide operating range.

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(52) **U.S. Cl.**

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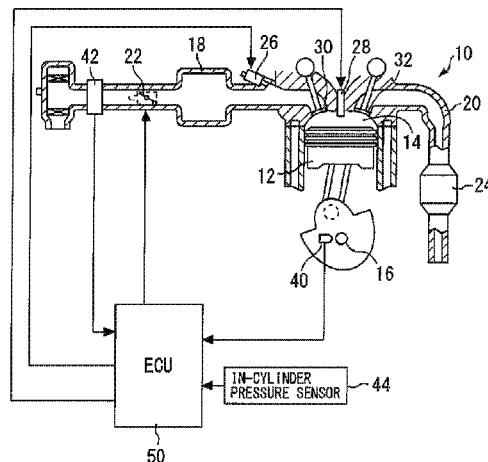
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CPC **F02D 35/023**; **F02D 41/222**; **F02D 41/22**; **F02D 19/025**; **F02D 19/0623**; **Y02T 10/40**

USPC 701/102, 103, 104, 105, 106, 107, 108, 701/109, 110, 111, 112, 113, 114, 115

See application file for complete search history.

6 Claims, 10 Drawing Sheets



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Fig. 1

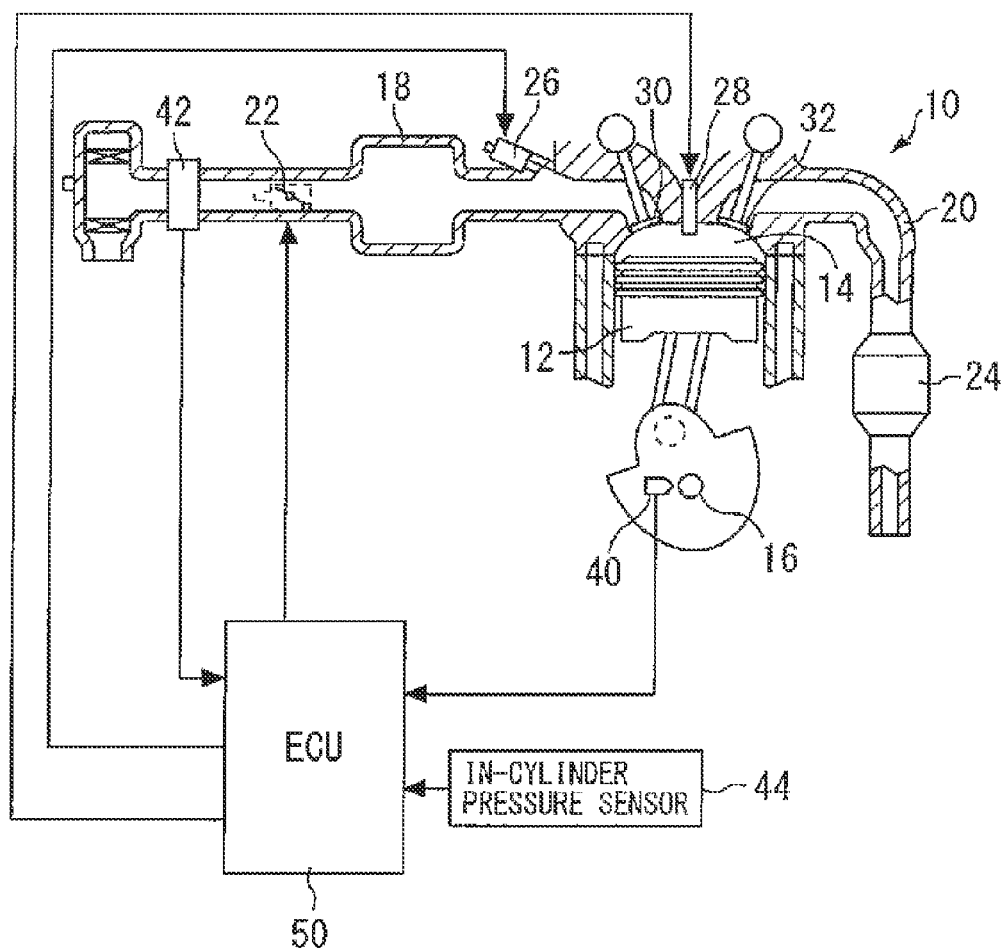


Fig. 2

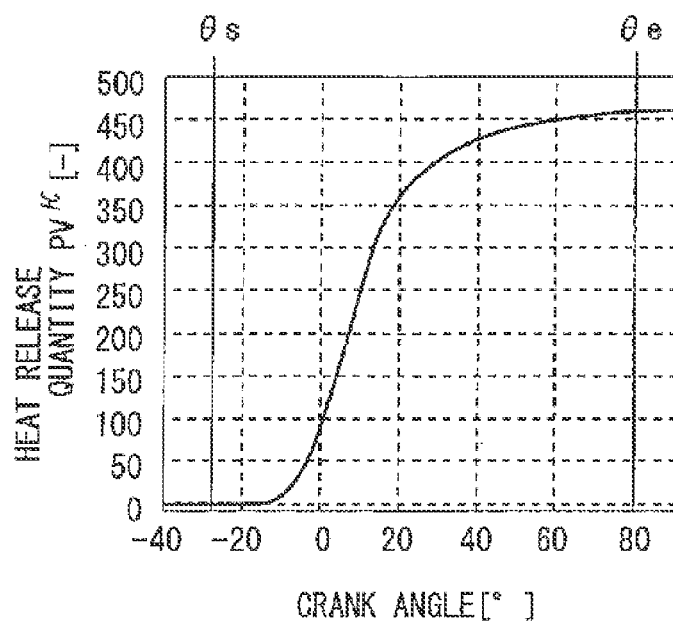


Fig. 3

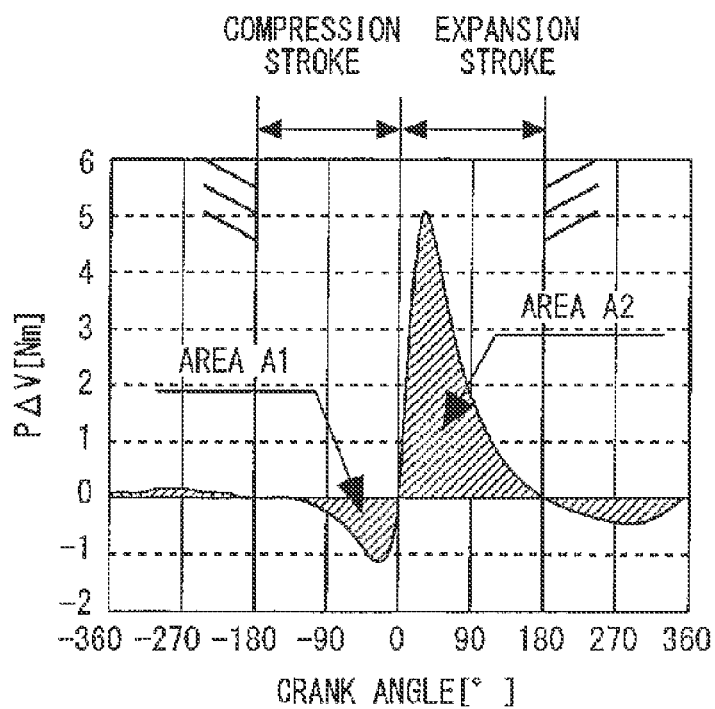


Fig. 4

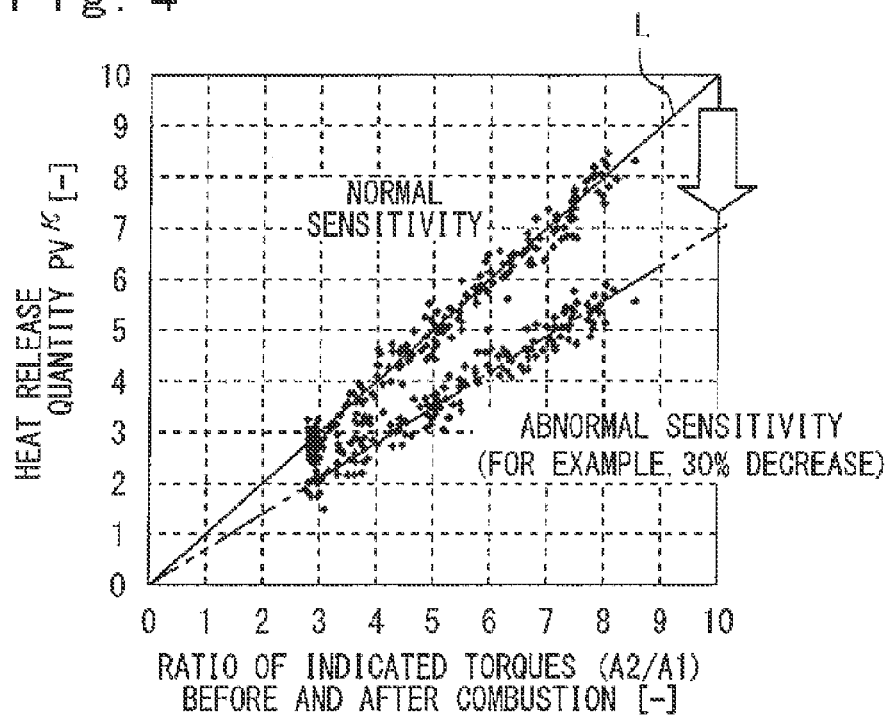


Fig. 5

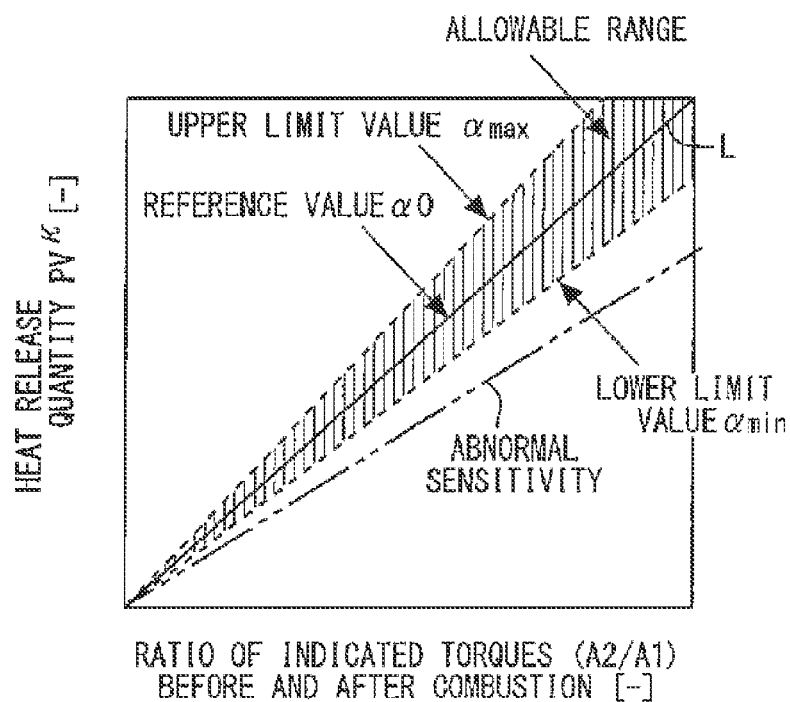


Fig. 6

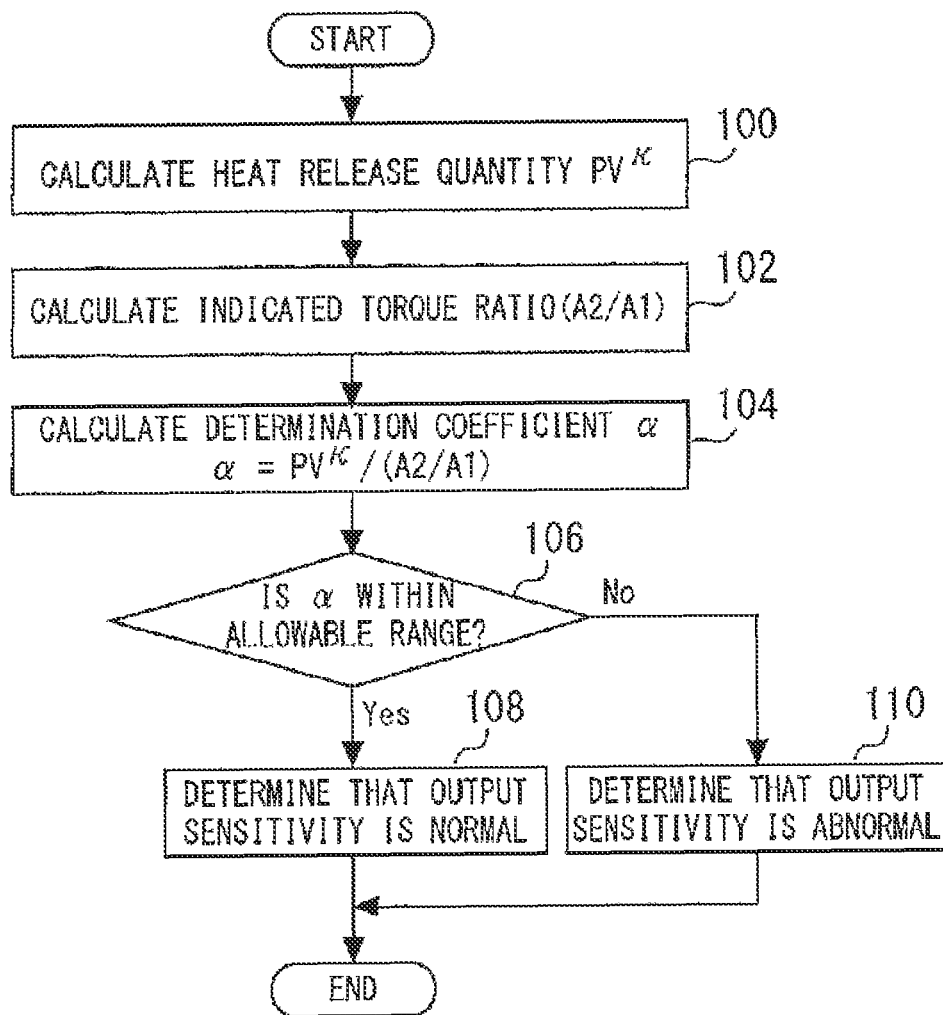


Fig. 7

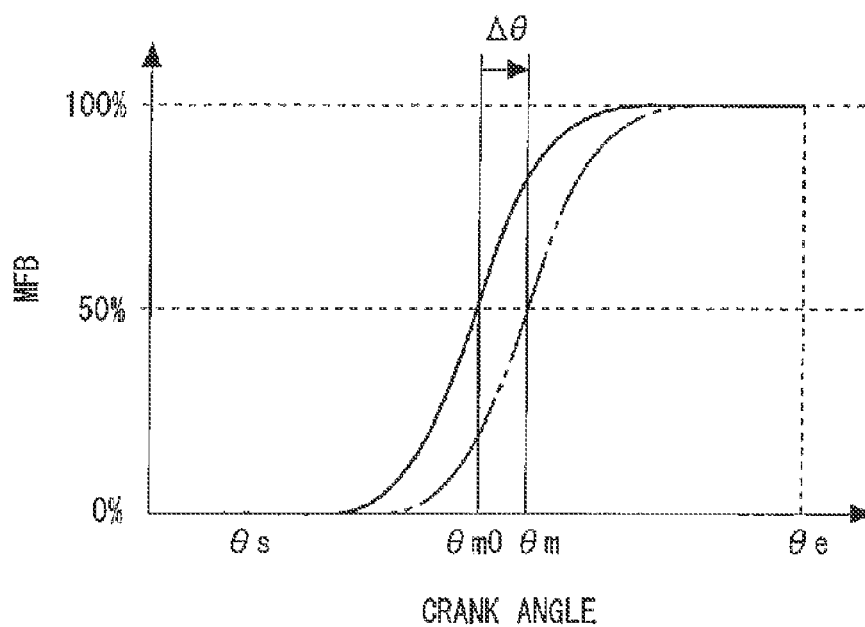


Fig. 8

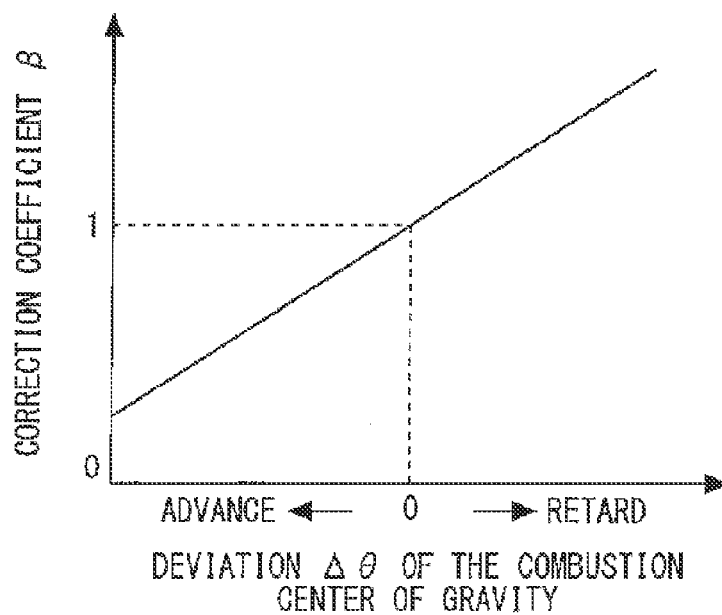


Fig. 9

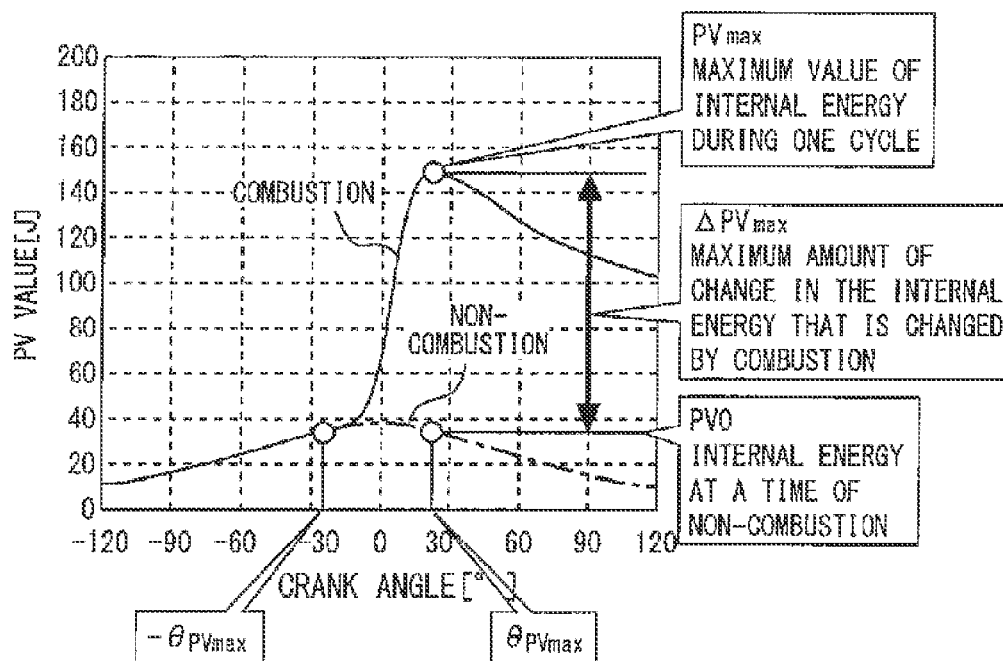


Fig. 10

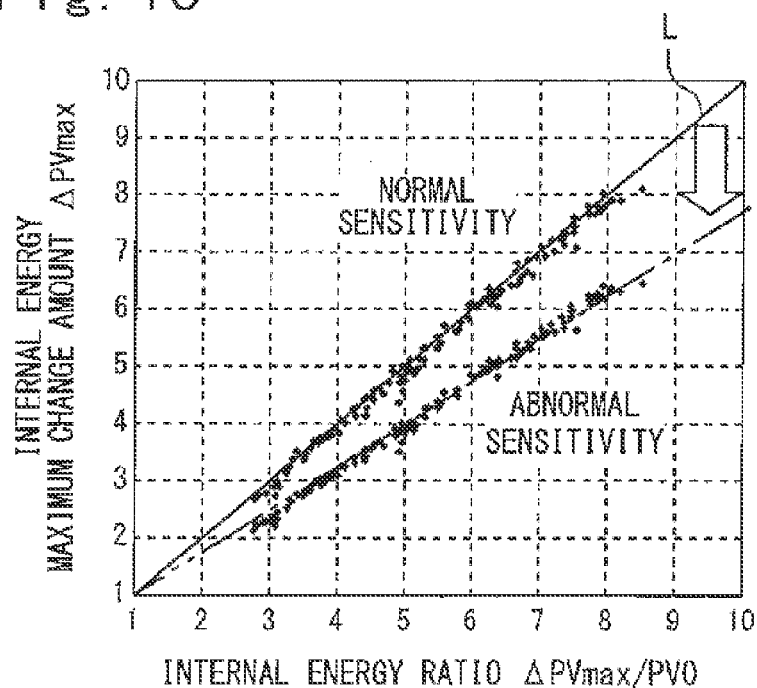


Fig. 11

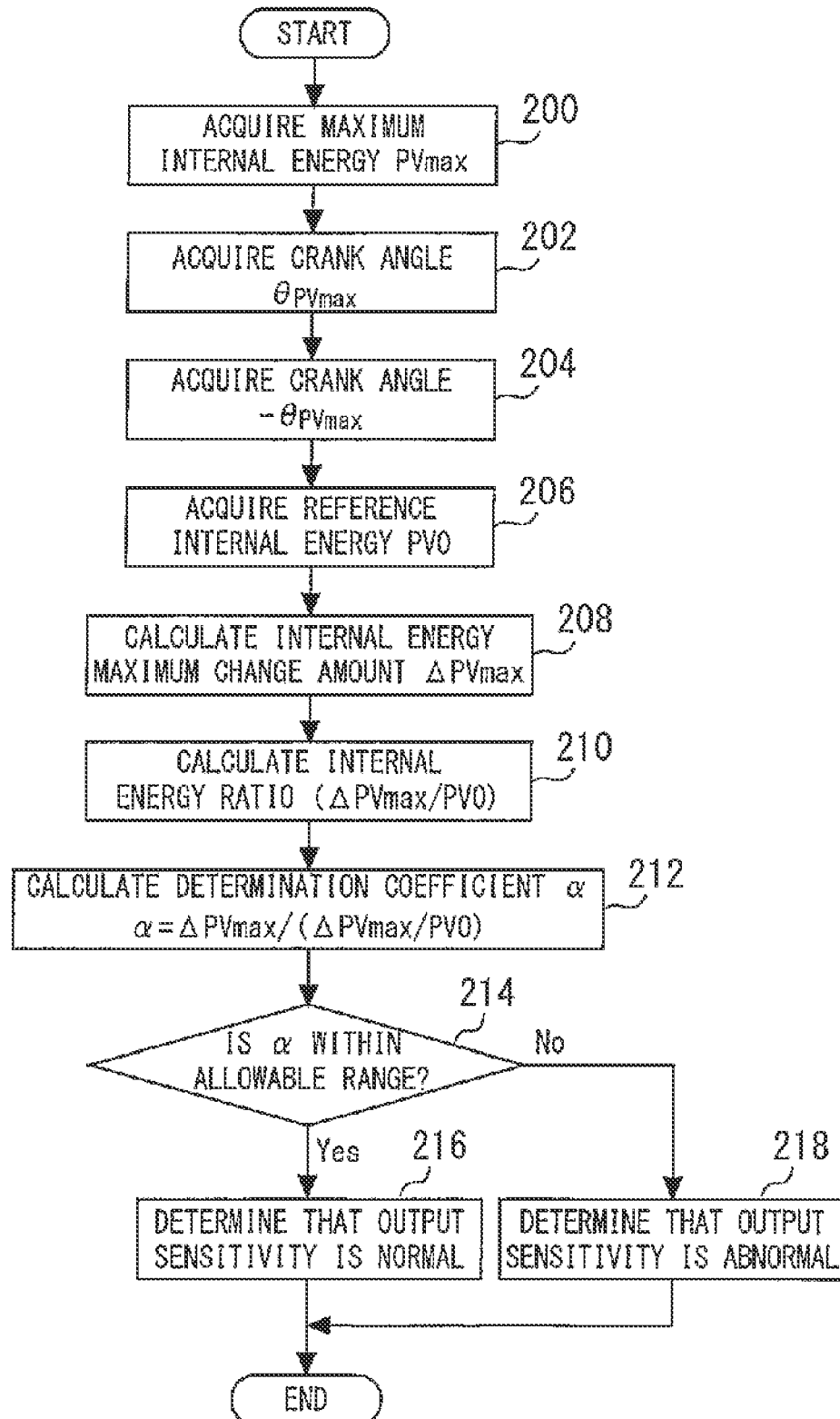


Fig. 12

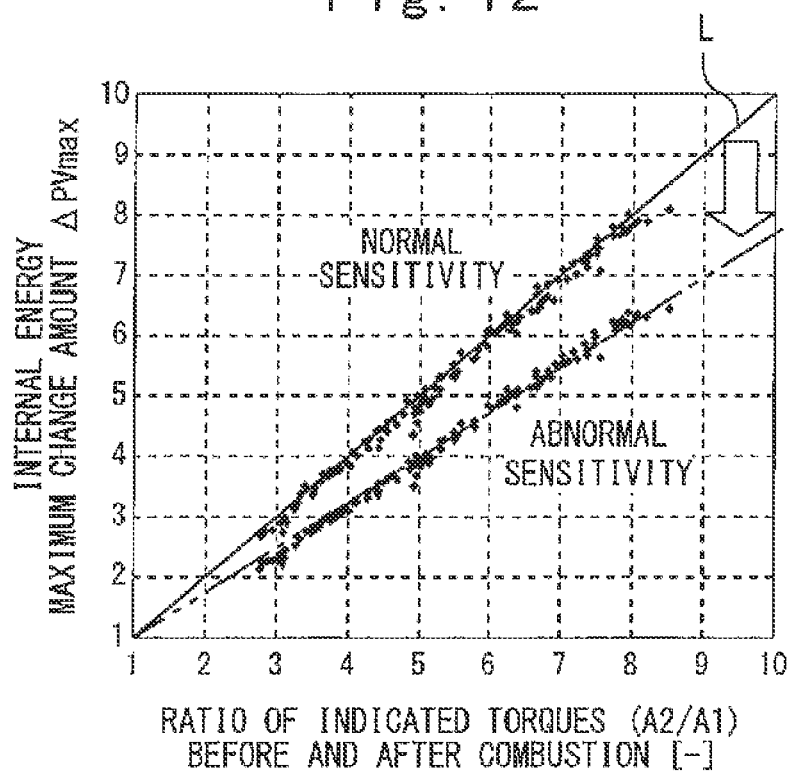


Fig. 13

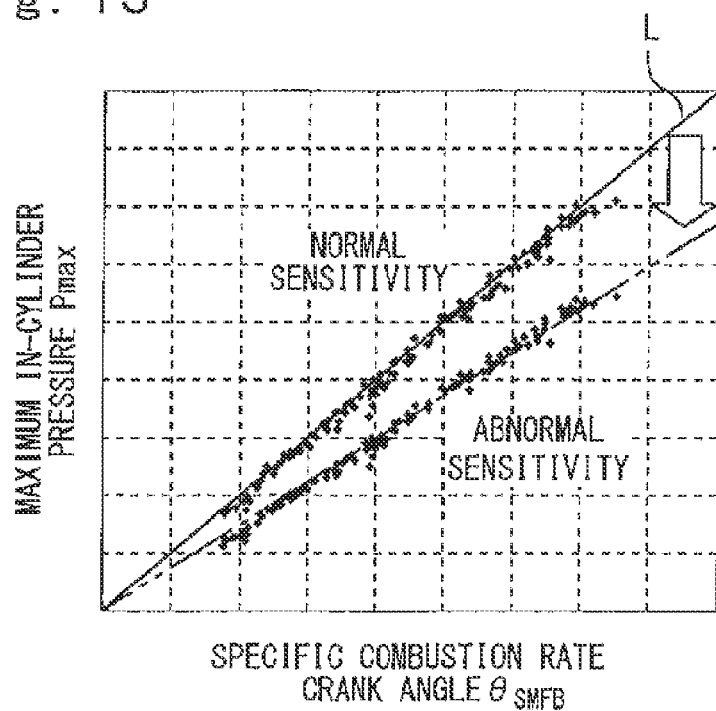


Fig. 14

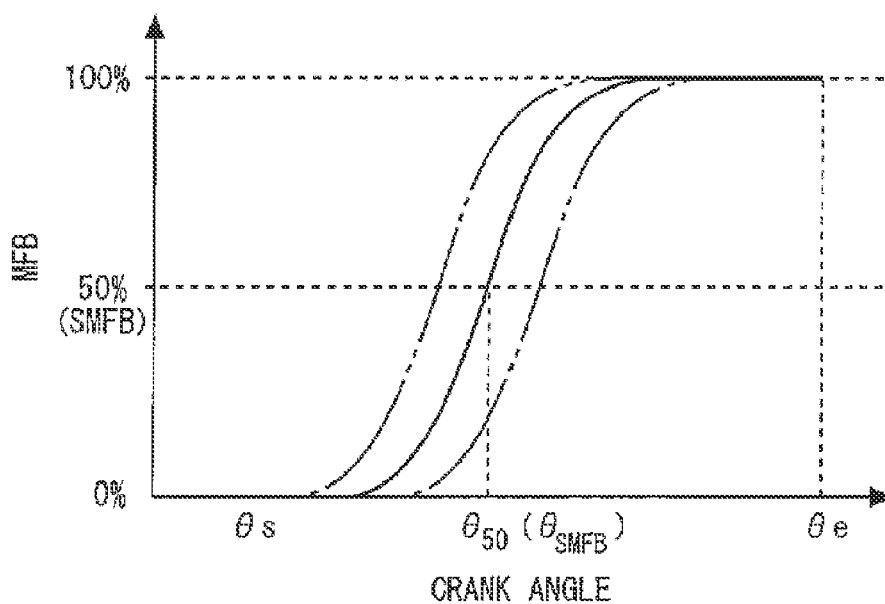
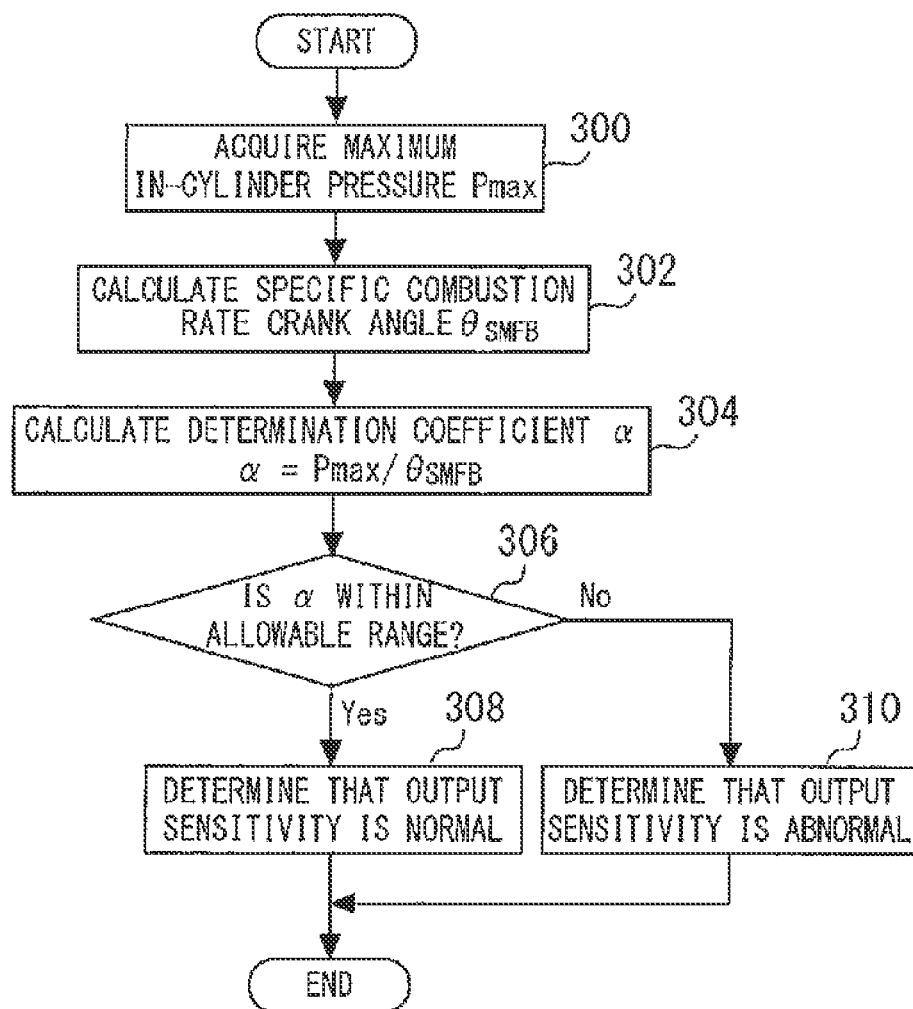


Fig. 15



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CONTROL APPARATUS FOR INTERNAL COMBUSTION ENGINE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a National Stage of International Application No. PCT/JP2011/060402 filed Apr. 28, 2011, the contents of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present invention relates to a control apparatus for an internal combustion engine, and more particularly to a control apparatus for an internal combustion engine that is equipped with a function for determining a failure of an in-cylinder pressure sensor.

BACKGROUND ART

Conventional technology relating to the present invention includes a control apparatus for an internal combustion engine that is equipped with a function for determining a failure of an in-cylinder pressure sensor, as disclosed, for example, in Patent Literature 1 (Japanese Patent Laid-Open No. 7-310585). According to the conventional technology, an in-cylinder pressure integrated value is calculated by integrating in-cylinder pressures detected by an in-cylinder pressure sensor in a predetermined integration interval. Further, a reference value is calculated that corresponds to an in-cylinder pressure integrated value in a normal combustion state on the basis of a basic fuel injection quantity, and a failure of the in-cylinder pressure sensor is determined by comparing the reference value and the aforementioned in-cylinder pressure integrated value.

The applicants are aware of the following literature, which includes the above described literature, as literature related to the present invention.

CITATION LIST

Patent Literature

- Patent Literature 1: Japanese Patent Laid-Open No. 7-310585
- Patent Literature 2: Japanese Patent Laid-Open No. 7-332152
- Patent Literature 3: Japanese Patent Laid-Open No. 7-318458
- Patent Literature 4: Japanese Patent Laid-Open No. 2010-133329
- Patent Literature 5: Japanese Patent Laid-Open No. 2010-127102
- Patent Literature 6: Japanese Patent Laid-Open No. 2005-248703

SUMMARY OF INVENTION

Technical Problem

According to the above described conventional technology it is necessary to previously prepare data (a data map or the like) for setting a reference value based on a basic fuel injection quantity. Consequently, there is the problem that an operating range in which fault determination is possible is restricted in accordance with an operating range that is set in

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the data map. In this respect, if it is attempted to execute fault determination with respect to all operating ranges, it is necessary to perform operations to determine reference values that are respectively adapted to a large number of base fuel injection quantities that correspond to all operating ranges, and consequently the man-hours required for data adaptation increase.

On the other hand, in a method that determines a fault by making a comparison with a reference value, it is difficult to distinguish between an environmental change of the engine (for example, a change in a compression ratio that arises due to accumulation of deposits) and a fault of the in-cylinder pressure sensor. Further, there are large variations in integrated values or maximum values (Pmax) or the like of the in-cylinder pressure for each combustion event, and there is a tendency for these values to change even when the operating states are the same. However, when a margin is added to the criterion for determining a fault in consideration of these points, it will lead to a drop in the determination accuracy.

The present invention has been conceived to solve the above described problems, and an object of the present invention is to provide a control apparatus for an internal combustion engine that is capable of accurately detecting a fault of an in-cylinder pressure sensor over a wide operating range without previously preparing a large amount of data or the like.

Means for Solving the Problem

A first aspect of the present invention is a control apparatus for an internal combustion engine, comprising:

an in-cylinder pressure sensor that outputs a signal corresponding to an in-cylinder pressure of the internal combustion engine;

first parameter acquisition means that acquires a first parameter which is acquired based on an output of the in-cylinder pressure sensor and which is affected by an output sensitivity of the sensor;

second parameter acquisition means that acquires a second parameter which has a correlation with the first parameter and which is not affected by the output sensitivity, and that calculates two indicators based on in-cylinder pressures obtained at different crank angles in an identical cycle and calculates the second parameter based on a ratio between the indicators; and

abnormality detection means that detects an abnormality of the output sensitivity of the in-cylinder pressure sensor based on a relationship between the first parameter and the second parameter.

In a second aspect of the present invention, further comprising:

indicated torque calculation means that, by integrating multiplication values obtained by multiplying an amount of change in an in-cylinder volume per unit crank angle by an in-cylinder pressure in a predetermined crank angle range, calculates an indicated torque corresponding to the crank angle range;

wherein:

the first parameter acquisition means acquires a heat release quantity PV^* that is calculated based on an in-cylinder pressure, an in-cylinder volume, and a ratio of specific heat as the first parameter; and

the second parameter acquisition means acquires a ratio between an indicated torque $A1$ that is calculated in a crank angle range corresponding to a compression stroke and an

indicated torque A2 that is calculated in a crank angle range corresponding to an expansion stroke as the second parameter.

In a third aspect of the present invention, further comprising:

determination criterion setting means that sets a determination criterion that a relationship between the first parameter and the second parameter should satisfy when the output sensitivity of the in-cylinder pressure sensor is normal; and

determination criterion correction means that corrects the determination criterion based on a deviation between a combustion center of gravity calculated in a cycle in which abnormality detection of the output sensitivity is performed and a reference combustion center of gravity that is previously set.

In a fourth aspect of the present invention, further comprising:

maximum internal energy calculation means that calculates a PV value by multiplying an in-cylinder pressure at an arbitrary crank angle by an in-cylinder volume at the crank angle, and acquires a maximum value of the PV value during one cycle as a maximum internal energy PVmax; and

reference internal energy calculation means that acquires a crank angle that is symmetrical about a top dead center position with a crank angle at which the maximum internal energy PVmax is obtained, and calculates the PV value at the crank angle as a reference internal energy PV0;

wherein:

the first parameter acquisition means acquires an internal energy maximum change amount ΔPV_{\max} that is obtained by subtracting the reference internal energy PV0 from the maximum internal energy PVmax as the first parameter; and

the second parameter acquisition means acquires a ratio ($\Delta PV_{\max}/PV0$) between the internal energy maximum change amount ΔPV_{\max} and the reference internal energy PV0 as the second parameter.

A fifth aspect of the present invention is a control apparatus for an internal combustion engine, further comprising:

indicated torque calculation means that, by integrating multiplication values obtained by multiplying an amount of change in an in-cylinder volume per unit crank angle by an in-cylinder pressure in a predetermined crank angle range, calculates an indicated torque corresponding to the crank angle range;

maximum internal energy calculation means that calculates a PV value by multiplying an in-cylinder pressure at an arbitrary crank angle by an in-cylinder volume at the crank angle, and acquires a maximum value of the PV value during one cycle as a maximum internal energy PVmax; and

reference internal energy calculation means that acquires a crank angle that is symmetrical about a top dead center position with a crank angle at which the maximum internal energy PVmax is obtained, and calculates the PV value at the crank angle as a reference internal energy PV0;

wherein:

the first parameter acquisition means acquires an internal energy maximum change amount ΔPV_{\max} that is obtained by subtracting the reference internal energy PV0 from the maximum internal energy PVmax as the first parameter; and

the second parameter acquisition means acquires a ratio ($A2/A1$) between an indicated torque A1 that is calculated in a crank angle range corresponding to a compression stroke and an indicated torque A2 that is calculated in a crank angle range corresponding to an expansion stroke as the second parameter.

In a sixth aspect of the present invention, further comprising:

MFB calculation means that calculates a heat release quantity PV^* based on an in-cylinder pressure, an in-cylinder volume, and a ratio of specific heat, and calculates a mass fraction of burned fuel at an arbitrary crank angle based on a ratio between a heat release quantity PV^* (θ_s) at a combustion start crank angle θ_s and a heat release quantity PV^* (θ_e) at a combustion end crank angle θ_e ;

wherein:

the first parameter acquisition means acquires a maximum in-cylinder pressure Pmax during one cycle as the first parameter; and

the second parameter acquisition means acquires a crank angle θ_{SMFB} at which the mass fraction of burned fuel matches a predetermined reference value SMFB as the second parameter.

Advantageous Effects of Invention

According to the first invention, based on only the output of the in-cylinder pressure sensor, it is possible to acquire a first parameter that is affected by the output sensitivity of the sensor, and a second parameter that is not affected by the output sensitivity. Thus, when an abnormality occurs in the output sensitivity of the in-cylinder pressure sensor, the relationship between the first parameter and the second parameter deviates from a normal state, and hence the abnormality of the output sensitivity can be reliably detected. Therefore, since another sensor output or the like need not be utilized in an auxiliary manner, the system can be simplified. Further, abnormality detection can be accurately performed without being affected by an output error of another sensor or the like. Furthermore, without previously preparing a large amount of data or the like, a sensitivity abnormality of the in-cylinder pressure sensor can be easily detected over a wide operating range, and the amount of data that is necessary for abnormality detection and the man-hours required for data adaptation can be suppressed.

According to the second invention, a heat release quantity PV^* that is a first parameter and a ratio between indicated torques A1 and A2 that is a second parameter can be calculated. Since the ratio between indicated torques A1 and A2 is not affected by the output sensitivity of the in-cylinder pressure sensor, an abnormality in the output sensitivity can be reliably detected based on the relationship between the first parameter and the second parameter.

According to the third invention, even if a deviation arises in the value of the heat release quantity PV^* due to a change in the combustion center of gravity, the determination criterion correction means can correct the determination criterion in accordance with the deviation. Therefore, even if the combustion center of gravity is changed by ignition timing control or the like, an abnormality in the sensitivity of the in-cylinder pressure sensor can be detected with high accuracy.

According to the fourth invention, an abnormality in the output sensitivity can be detected based on the relationship between an internal energy maximum change amount ΔPV_{\max} that is a first parameter and an internal energy ratio ($\Delta PV_{\max}/PV0$) that is a second parameter. Since the internal energy maximum change amount ΔPV_{\max} is the amount of change in the internal energy that is generated by combustion, it can absorb a variation in the heat release quantity caused by changes in the combustion center of gravity and the like. Therefore, even if the combustion center of gravity changes, an abnormality in the sensitivity of the in-cylinder

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pressure sensor can be accurately detected. Further, the internal energy maximum change amount ΔPV_{\max} can be acquired at a crank angle that is further to the spark advance side than a combustion end crank angle. Accordingly, a sensitivity abnormality can be detected at a timing at which the detection operation is less apt to be affected by a thermal strain error that arises in the in-cylinder pressure sensor, and thus the detection accuracy can be improved.

According to the fifth invention, an abnormality in the output sensitivity can be detected based on the relationship between the internal energy maximum change amount ΔPV_{\max} as a first parameter and the ratio between indicated torques $A1$ and $A2$ as a second parameter.

According to the sixth invention, an abnormality in the output sensitivity can be detected based on the relationship between the maximum in-cylinder pressure P_{\max} that is a first parameter, and a crank angle θ_{SMFB} at which the mass fraction of burned fuel becomes a predetermined reference value $SMFB$ that is a second parameter. Therefore, the crank angle θ_{SMFB} can be calculated at a timing that is further to the spark advance side than the actual combustion end point, that is, at a timing before a thermal strain error starts to arise. Similarly, since the maximum in-cylinder pressure P_{\max} also occurs at a timing that is further to the spark advance side than the actual combustion end point, the maximum in-cylinder pressure P_{\max} is less apt to be affected by a thermal strain error. Further, since the crank angle θ_{SMFB} at which the mass fraction of burned fuel becomes a predetermined reference value $SMFB$ is used as the second parameter, even if the combustion center of gravity changes due to ignition timing control or the like, the second parameter is not affected by such a change. Accordingly, the output sensitivity of the in-cylinder pressure sensor can be accurately detected.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a configuration diagram for explaining the system configuration of Embodiment 1 of the present invention.

FIG. 2 is a characteristics diagram that illustrates the relationship between the heat release quantity PV^* that is the first parameter and the crank angle.

FIG. 3 is a characteristics diagram that illustrates indicated torques before and after combustion that are used to calculate the indicated torque ratio ($A2/A1$).

FIG. 4 is a characteristics diagram that shows the relationship between the heat release quantity PV^* and the indicated torque ratio ($A2/A1$).

FIG. 5 is an explanatory view that illustrates an allowable range of the determination coefficient α in the form of slopes of characteristic lines.

FIG. 6 is a flowchart that illustrates control executed by the ECU according to Embodiment 1 of the present invention.

FIG. 7 is a characteristics diagram that shows changes in the combustion center of gravity that are caused by ignition timing control or the like according to Embodiment 2 of the present invention.

FIG. 8 is a view that illustrates a data map for calculating the correction coefficient β of the allowable range based on the deviation $\Delta\theta$ of the combustion center of gravity.

FIG. 9 is a characteristics diagram that shows changes in PV values before and after combustion, according to Embodiment 3 of the present invention.

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FIG. 10 is a characteristics diagram that illustrates the relationship between the internal energy maximum change amount ΔPV_{\max} and the internal energy ratio ($\Delta PV_{\max}/PV_0$).

FIG. 11 is a flowchart that illustrates control executed by the ECU according to Embodiment 3 of the present invention.

FIG. 12 is a characteristics diagram that shows the relationship between the internal energy maximum change amount ΔPV_{\max} and the indicated torque ratio ($A2/A1$) according to Embodiment 4 of the present invention.

FIG. 13 is a characteristics diagram that shows the relationship between the maximum in-cylinder pressure P_{\max} and a specific combustion rate crank angle θ_{SMFB} according to Embodiment 5 of the present invention.

FIG. 14 is an explanatory view that shows, for example, a specific combustion rate crank angle θ_{50} in a case where $SMFB=50\%$ in a characteristics diagram of the mass fraction of burned fuel.

FIG. 15 is a flowchart that illustrates control executed by the ECU according to Embodiment 5 of the present invention.

DESCRIPTION OF EMBODIMENTS

Embodiment 1

[Configuration of Embodiment 1]

Hereunder, Embodiment 1 of the present invention is described while referring to FIGS. 1 to 6. FIG. 1 is a configuration diagram for explaining the system configuration of Embodiment 1 of the present invention. The system of the present embodiment includes an engine 10 as a multi-cylinder internal combustion engine. Although only one cylinder of the engine 10 is shown in FIG. 1, the present invention may be applied to an engine with an arbitrary number of cylinders including an engine with a single cylinder. In each cylinder of the engine 10, a combustion chamber 14 is defined by a piston 12, and the piston 12 is connected to a crankshaft 16 of the engine.

The engine 10 also includes an intake passage 18 that draws intake air into the combustion chamber 14 (inside the cylinder) of each cylinder, and an exhaust passage 20 through which exhaust gas is discharged from each cylinder. An electronically controlled throttle valve 22 that adjusts an intake air amount based on a degree of accelerator opening or the like is provided in the intake passage 18. A catalyst 24 that purifies exhaust gas is provided in the exhaust passage 20. Each cylinder is provided with a fuel injection valve 26 that injects fuel into an intake port, a spark plug 28 that ignites an air-fuel mixture in the cylinder, an intake valve 30 that opens and closes the intake port with respect to the inside of the cylinder, and an exhaust valve 32 that opens and closes an exhaust port with respect to the inside of the cylinder.

The system of the present embodiment also includes a sensor system including sensors 40 to 44, and an ECU (Electronic Control Unit) 50 that controls an operating state of the engine 10. A crank angle sensor 40 outputs a signal that is synchronous with rotation of a crankshaft 16. An airflow sensor 42 detects an intake air amount. Further, an in-cylinder pressure sensor 44 is constituted, for example, by a known pressure sensor that has a piezoelectric element or the like, and detects a signal corresponding to an in-cylinder pressure. One in-cylinder pressure sensor 44 is provided in each cylinder. The sensor system also includes various sensors that are required for engine control (a throttle sensor that detects the degree of opening of the throttle valve 22, a

water temperature sensor that detects the temperature of engine cooling water, an air-fuel ratio sensor that detects the exhaust air-fuel ratio, and the like).

The ECU 50 is constituted by, for example, an arithmetic processing apparatus that is equipped with a storage circuit including a ROM, a RAM, a non-volatile memory, or the like. Each sensor of the sensor system is connected to an input side of the ECU 50. Various actuators including the throttle valve 22, the fuel injection valve 26, and the spark plug 28 are connected to an output side of the ECU 50. The ECU 50 is equipped with a function that stores various kinds of data that change according to the crank angle as time-series data together with the relevant crank angle. This time-series data includes an output value of the in-cylinder pressure sensor 44 and various parameters that are calculated based on the relevant output value and the like.

The ECU 50 controls the operating state of the engine by driving each actuator while detecting engine operating information by means of the sensor system. More specifically, the ECU 50 detects the number of engine revolutions and the crank angle based on the output of the crank angle sensor 40, and calculates an intake air amount based on the output of the airflow sensor 42. The ECU 50 also calculates the engine load (load factor) based on the intake air amount and the number of engine revolutions and the like. The ECU 50 determines the fuel injection timing and the ignition timing based on the crank angle, and drives the fuel injection valve 26 or the spark plug 28 when these timings are reached. Thus, an air-fuel mixture inside the cylinders can be burned to operate the engine. The ECU 50 also executes known combustion control and detects knocking or pre-ignition and the like based on the output of the in-cylinder pressure sensor 44.

[Features of Embodiment 1]

A feature of the present embodiment is that an abnormality in the output sensitivity of the in-cylinder pressure sensor 44 is detected based on the output of the sensor. In this case, with respect to abnormality detection methods according to the conventional technology, as a first example of the conventional technology, a method is known that detects an abnormality in the output sensitivity of an in-cylinder pressure sensor based on outputs of other sensors such as an intake air pressure sensor, an airflow sensor, and an A/F sensor. Further, as a second example of the conventional technology, a method is known that detects an abnormality in the output sensitivity of an in-cylinder pressure sensor by previously storing a normal output of the in-cylinder pressure sensor under specific operating conditions as a reference value, and detecting the existence of an abnormality based on the reference value.

However, according to the first example of the conventional technology, because the accuracy of detecting an abnormality depends on the accuracy of the sensors that serve as a reference, abnormality detection cannot be performed when there is a fault at a sensor that serves as a reference. Further, according to the second detection method, it is necessary to either limit an operating condition (operating range) under which to perform abnormality detection or to perform operations to adapt a reference value to all operating ranges, and therefore either the opportunities to carry out abnormality detection are limited or the man-hours required for adaptation of the reference value increase. Further, since there are variations in reference values even under the same operating conditions, the accuracy of detecting an abnormality decreases.

Therefore, according to the present embodiment two kinds of parameters (first and second parameters) with

mutually different characteristics are acquired on the basis of the output of the in-cylinder pressure sensor 44, and an abnormality in the output sensitivity of the in-cylinder pressure sensor is detected based on the relationship between these parameters. In this case, although the first and second parameters have a fixed correlation with each other, the first parameter has a characteristic that is affected by the output sensitivity of the in-cylinder pressure sensor, and the second parameter has a characteristic that is not affected by the output sensitivity. Accordingly, since the relationship between the two parameters changes from a state at a normal time if an abnormality arises in the output sensitivity, the abnormality in the output sensitivity can be detected based on only the output of the in-cylinder pressure sensor. In this connection, the first and second parameters are acquired in the same cycle.

According to the present embodiment, a heat release quantity PV^{κ} is acquired as the first parameter and an indicated torque ratio ($A2/A1$) is acquired as the second parameter. When a determination coefficient α that is a ratio between the first and second parameters deviates from an allowable range, it is determined that the output sensitivity is abnormal. These processes are described specifically hereunder.

(First Parameter)

FIG. 2 is a characteristics diagram that illustrates the relationship between the heat release quantity PV^{κ} that is the first parameter and the crank angle. In FIG. 2, θ_s denotes a combustion start crank angle and θ_e denotes a combustion end crank angle. Although the combustion start crank angle θ_s is a crank angle immediately after ignition, the combustion start crank angle θ_s may be set as a crank angle before ignition for calculation purposes. The combustion end crank angle θ_e is set to a crank angle at which combustion normally ends (for example, approximately ATDC 80°). Note that, in the following description, it is assumed that a crank angle of 0° (°CA) corresponds to top dead center (TDC).

Since the heat release quantity PV^{κ} corresponds to a heat quantity generated in a cylinder, as shown in FIG. 2, the heat release quantity PV^{κ} increases in the direction of the combustion end crank angle θ_e from the combustion start crank angle θ_s , and reaches a maximum in the vicinity of the combustion end crank angle θ_e . The heat release quantity PV^{κ} is calculated by multiplying an in-cylinder pressure P detected by the in-cylinder pressure sensor 44 at an arbitrary crank angle by a value V^{κ} obtained by exponentiating an in-cylinder volume V at the relevant crank angle by a ratio of specific heat κ . Accordingly, since the heat release quantity PV^{κ} includes an absolute value of the in-cylinder pressure P as it is, the heat release quantity PV^{κ} is a parameter that is affected by the output sensitivity of the in-cylinder pressure sensor, and fluctuates in accordance with an error in the output sensitivity.

Further, an offset component that changes in accordance with the amount of air inside the cylinder and the like is included in the value calculated for the heat release quantity PV^{κ} . Therefore, the heat release quantity PV^{κ} that is used as the first parameter is calculated in a state in which an offset that would constitute an error has been removed by subtracting the heat release quantity PV^{κ} at the combustion start crank angle θ_s from the heat release quantity PV^{κ} at the combustion end crank angle θ_e . FIG. 2 shows heat release quantities PV^{κ} in a state in which an offset component has been removed.

(Second Parameter)

Next, the indicated torque ratio ($A2/A1$) that is the second parameter is described. FIG. 3 is a characteristics diagram that illustrates indicated torques before and after combustion that are used to calculate the indicated torque ratio ($A2/A1$). According to the present embodiment, an indicated torque $A1$ in a compression stroke and an indicated torque $A2$ in an expansion stroke are calculated as the indicated torques before and after combustion, respectively. As shown in FIG. 3, the indicated torque $A1$ (area $A1$) in the compression stroke is calculated by integrating multiplication values ($P\Delta V$) obtained by multiplying a variation ΔV in the in-cylinder volume per unit crank angle by the in-cylinder pressure P with respect to a crank angle range (-180° to 0°) corresponding to the compression stroke. The indicated torque $A2$ (area $A2$) in the expansion stroke is calculated by integrating the multiplication values $P\Delta V$ with respect to a crank angle range corresponding to the expansion stroke (0° to 180°).

The indicated torque ratio ($A2/A1$) is calculated as a ratio of the indicated torque $A2$ in the expansion stroke to the indicated torque $A1$ in the compression stroke. More specifically, according to the present embodiment, two indicators $A1$ and $A2$ are calculated based on in-cylinder pressures P and the like that are obtained at different crank angles (-180° to 0°) and (0° to 180°) in the same cycle, and an indicated torque ratio ($A2/A1$) is calculated based on the ratio between the indicators. Since the indicated torque ratio ($A2/A1$) obtained in this manner includes the in-cylinder pressure P in the denominator and the numerator thereof, respectively, a change in the output sensitivity of the in-cylinder pressure sensor is cancelled out between the denominator and the numerator, and thus the parameter is one that is not affected by the output sensitivity. In this connection, the in-cylinder volumes V at arbitrary crank angles and the variations ΔV per unit crank angle thereof are previously stored as a data map or the like in the ECU 50. (Sensitivity Abnormality Detection Processing)

Next, processing that detects an abnormality in the output sensitivity based on the first and second parameters is described while referring to FIG. 4 and FIG. 5. FIG. 4 is a characteristics diagram that shows the relationship between the heat release quantity PV^k and the indicated torque ratio ($A2/A1$). In general, since that is a correlation between a heat release quantity inside a cylinder and the generated amount of torque, for example, a proportionality relationship as shown by a characteristic line L in FIG. 4 holds between the heat release quantity PV^k and the ratio of indicated torques ($A2/A1$) before and after combustion. In this case, it is assumed that the characteristic line L is a characteristic line (reference characteristic line) in a case where the output sensitivity of the in-cylinder pressure sensor matches the design value. When a deviation does not arise in the output sensitivity, under an arbitrary operating condition a ratio between the heat release quantity PV^k and the indicated torque ratio ($A2/A1$) is a value that corresponds to the slope of the reference characteristic line L .

In contrast, a hypothetical line in FIG. 4 shows a characteristic line that is obtained when the output sensitivity of the sensor deviates from the design value (for example, in the case of a 30% decrease). When a deviation arises in the output sensitivity of the sensor, although the value of the heat release quantity PV^k is affected by the deviation and fluctuates, the value of the indicated torque ratio ($A2/A1$) is not affected by the deviation, and hence the ratio between the two values (slope of the characteristic line) changes.

Therefore, according to the present embodiment, as shown in the following equation (1), the ratio between the heat release quantity PV^k and the indicated torque ratio ($A2/A1$) is calculated as a determination coefficient α , and when the determination coefficient α deviates from a predetermined allowable range, the output sensitivity of the in-cylinder pressure sensor is determined to be abnormal.

$$\alpha = PV^k / (A2/A1) \quad (1)$$

FIG. 5 is an explanatory view that illustrates an allowable range of the determination coefficient α in the form of slopes of characteristic lines. The allowable range of the determination coefficient α corresponds to a range of output sensitivities of the in-cylinder pressure sensor that are practically allowable, and constitutes a determination criterion that the determination coefficient α should satisfy when the output sensitivity is normal. This allowable range is set by means of an upper limit value α_{max} and a lower limit value α_{min} that are previously stored in the ECU 50. The upper limit value α_{max} and lower limit value α_{min} are, for example, set as values obtained by increasing and decreasing the slope of the reference characteristic line L (reference value $\alpha(0)$) at a fixed rate. In the processing to detect a sensitivity abnormality, when the determination coefficient α calculated by the above equation (1) is within the allowable range, that is, when the expression $\alpha_{max} \geq \alpha \geq \alpha_{min}$ holds, it is determined that the output sensitivity of the in-cylinder pressure sensor is normal. Further, when the determination coefficient α deviates from the allowable range, as in the case of a characteristic line illustrated by the hypothetical line in FIG. 5 for example, it is determined that the output sensitivity of the sensor is abnormal.

[Specific Processing to Realize Embodiment 1]

Next, specific processing for implementing the above described control is described with reference to FIG. 6. FIG. 6 is a flowchart that illustrates control executed by the ECU according to Embodiment 1 of the present invention. It is assumed that the routine shown in FIG. 6 is repeatedly executed during operation of the engine. According to the routine shown in FIG. 6, first, in step 100, for example, a heat release quantity PV^k from which an offset component is removed is calculated by subtracting a heat release quantity PV^k at the combustion start crank angle θ_s from a heat release quantity PV^k at the combustion end crank angle θ_e .

Next, in step 102, the indicated torque $A1$ in the compression stroke and the indicated torque $A2$ in the expansion stroke are calculated, and are used to calculate the indicated torque ratio ($A2/A1$). In this connection, in the calculation processing of steps 100 and 102, the heat release quantity PV^k is calculated when the crank angle reaches the combustion end crank angle θ_e , and the indicated torque ratio ($A2/A1$) is calculated by integration processing over a single cycle. These calculation processes may also be executed, for example, after the end of the expansion stroke, based on time-series data for the in-cylinder pressure or the like that is stored in the ECU 50.

Next, in step 104, the determination coefficient α is calculated by the aforementioned equation (1), and in step 106 the ECU 50 determines whether or not the determination coefficient α falls within the allowable range. If the result determined in step 106 is affirmative, that is, when the expression $\alpha_{max} \geq \alpha \geq \alpha_{min}$ holds, in step 108 the ECU 50 determines that the output sensitivity of the in-cylinder pressure sensor is normal. In contrast, if the result determined in step 106 is negative, in step 110, the ECU 50 determines that the output sensitivity is abnormal.

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As described above, according to the present embodiment, based on the output of the in-cylinder pressure sensor 44, the heat release quantity PV^k that is affected by the output sensitivity of the sensor, and the indicated torque ratio ($A2/A1$) that is not affected by the output sensitivity are calculated, and an abnormality in the output sensitivity can be detected based on the determination coefficient α that is a ratio between the two calculated values. Therefore, since another sensor output or the like need not be utilized in an auxiliary manner, a sensitivity abnormality can be detected based on only the output of the in-cylinder pressure sensor, and thus the system can be simplified. Further, abnormality detection can be accurately performed without being affected by an output error of another sensor or the like.

In addition, since the determination coefficient α can be calculated under an arbitrary operating condition (operating range), even without previously preparing a large amount of data or the like, a sensitivity abnormality of the in-cylinder pressure sensor can be easily detected over a wide operating range. Accordingly, the amount of data required for abnormality detection or the man-hours required for data adaptation can be suppressed. Further, since maximum values of in-cylinder pressure or the like in which variations are liable to arise during each combustion are not used, a margin added to the criterion for determining a sensitivity abnormality (allowable range of the determination coefficient α) can be set to a minimum amount, and the determination accuracy can be improved.

Note that, in the above described Embodiment 1, step 100 in FIG. 6 shows a specific example of first parameter acquisition means according to claims 1 and 2 and step 102 shows a specific example of second parameter acquisition means. Further, steps 104, 106, 108, and 110 show a specific example of abnormality detection means. Furthermore, the characteristics diagram shown in FIG. 3 shows a specific example of indicated torque calculation means according to claim 2, and the characteristics diagram shown in FIG. 5 constitutes a specific example of determination criterion setting means according to claim 3.

Embodiment 2

Next, Embodiment 2 of the present invention is described with reference to FIG. 7 and FIG. 8. A feature according to the present embodiment is that, with respect to the same configuration and control as the above described Embodiment 1, an allowable range of the determination coefficient is corrected in accordance with changes in the combustion center of gravity. According to the present embodiment, components that are the same as in Embodiment 1 are denoted by the same reference symbols, and a description of such components is omitted.

[Features of Embodiment 2]

In general, when the combustion center of gravity is changed as the result of ignition timing control or the like, a heat release quantity inside the cylinder also changes in accompaniment therewith. More specifically, for example, when the ignition timing is retarded, the combustion efficiency changes and afterburning of unburned fuel and the like increases, and consequently the heat release quantity increases. Therefore, if the determination coefficient α is calculated on the premise that the combustion center of gravity is constant, a case may occur in which a deviation arises in the calculated value. In FIG. 4 of Embodiment 1, the reason that variations exist in the data with respect to the reference characteristic line L is mainly because there are changes in the combustion center of gravity. Therefore, according to the present embodiment, the allowable range (upper limit value α_{max} and lower limit value α_{min}) of the

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determination coefficient α is corrected in accordance with changes in the combustion center of gravity.

FIG. 7 is a characteristics diagram that shows changes in the combustion center of gravity that are caused by ignition timing control or the like according to Embodiment 2 of the present invention. A characteristic line shown in FIG. 7 represents a mass fraction of burned fuel MFB that is calculated by equation (2) below, for which the combustion center of gravity θ_m is defined as a crank angle θ at which the MFB=50%. In the following equation (2), $PV^k(\theta)$, $PV^k(\theta_s)$ and $PV^k(\theta_e)$ denote a heat release quantity PV^k at a crank angle θ , the combustion start crank angle θ_s , and the combustion end crank angle θ_e , respectively.

$$MFB(\%) = \frac{PV^k(\theta) - PV^k(\theta_e)}{PV^k(\theta_s) - PV^k(\theta_e)} \quad (2)$$

As shown in FIG. 7, the combustion center of gravity θ_m changes in accordance with the ignition timing or the like. Therefore, according to the present embodiment, the combustion center of gravity θ_m is calculated in a cycle in which the output sensitivity of the in-cylinder pressure sensor is assessed, and a deviation $\Delta\theta$ between the calculated combustion center of gravity θ_m and a reference combustion center of gravity θ_{m0} is calculated by the following equation (3). In this case, the reference combustion center of gravity θ_{m0} is a value that serves as a reference when setting the allowable range of the determination coefficient α , and the upper limit value α_{max} and lower limit value α_{min} that are boundary values of the allowable range are set on the premise that the combustion center of gravity is α_{m0} .

$$\Delta\theta = \theta_m - \theta_{m0} \quad (3)$$

In the subsequent processing, based on the deviation $\Delta\theta$ of the combustion center of gravity, a correction coefficient β of the allowable range is calculated by referring to a data map (FIG. 8), described later, that is previously stored in the ECU 50. Next, based on the calculated correction coefficient β , the upper limit value α_{max} and lower limit value α_{min} are corrected by means of the following equations (4) and (5), to thereby calculate a corrected upper limit value α_{max}' and a corrected lower limit value α_{min}' . Subsequently, using the corrected upper limit value α_{max}' and corrected lower limit value α_{min}' , the ECU 50 determines whether or not the determination coefficient α falls within the allowable range.

$$\alpha_{max}' = \alpha_{max} \times \beta \quad (4)$$

$$\alpha_{min}' = \alpha_{min} \times \beta \quad (5)$$

FIG. 8 is a view that illustrates a data map for calculating the correction coefficient β of the allowable range based on the deviation $\Delta\theta$ of the combustion center of gravity. As described above, the greater the degree to which the combustion center of gravity (ignition timing) is retarded, the greater the increase in the heat release quantity PV^k , and therefore the slope of the characteristic line L shown in the above described FIG. 4 and FIG. 5 and the calculated value of the determination coefficient α also deviate in the increasing direction in accompaniment therewith. Therefore, according to the present embodiment, as shown in FIG. 8, the greater the degree to which the combustion center of gravity θ_m is retarded, the greater the degree to which the correction coefficient β is increased and the corrected upper limit value α_{max}' and lower limit value α_{min}' are corrected in the increasing direction.

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Thus, according to the present embodiment, in addition to the same operational advantages of the foregoing Embodiment 1, it is possible to correct the allowable range in accordance with a deviation of the determination coefficient α , and to cancel out affects generated by a change in the combustion center of gravity. Therefore, even if the combustion center of gravity is changed by ignition timing control or the like, an abnormality in the output sensitivity of the in-cylinder pressure sensor 44 can be detected with high accuracy. Note that, as specific processing for implementing Embodiment 2, for example, relative to the processing of Embodiment 1 (FIG. 6), before executing the processing of step 106, the corrected upper limit value α_{max}' and lower limit value α_{min}' are calculated based on the above described processing. Subsequently, in step 106, it is sufficient to determine whether or not the expression $\alpha_{max}' \geq \alpha \geq \alpha_{min}'$ holds. Further, in Embodiment 2, the data map shown in FIG. 8 and the above described equations (4) and (5) show a specific example of determination criterion correction means according to claim 3.

Embodiment 3

Next, Embodiment 3 of the present invention is described with reference to FIG. 9 to FIG. 11. A feature according to the present embodiment is that parameters that are different to the parameters of the above described Embodiment 1 are used as the first and second parameters. According to the present embodiment, components that are the same as in Embodiment 1 are denoted by the same reference symbols, and a description of such components is omitted. [Features of Embodiment 3]

FIG. 9 is a characteristics diagram that shows changes in PV values before and after combustion, according to Embodiment 3 of the present invention. The term "PV value" refers to a value that is obtained by multiplying an in-cylinder pressure P at an arbitrary crank angle by an in-cylinder volume V at the relevant crank angle, and that corresponds to an amount of internal energy in a cylinder. According to the present embodiment, attention is focused on the PV value to acquire first and second parameters. More specifically, an internal energy maximum change amount ΔPV_{max} is acquired as a first parameter and an internal energy ratio ($\Delta PV_{max}/PV0$) is acquired as a second parameter. These parameters are described specifically hereunder. (First Parameter)

As shown in FIG. 9, the PV value rapidly increases when combustion begins, and reaches a maximum at a crank angle $\theta_{PV_{max}}$ before combustion ends. According to the present embodiment, the maximum value of the PV value is acquired as a maximum internal energy PV_{max} . The maximum internal energy PV_{max} corresponds to the maximum value of internal energy during one cycle. The crank angle $\theta_{PV_{max}}$ at which the maximum internal energy PV_{max} is obtained is a crank angle that is further to the spark advance side than a crank angle (combustion end crank angle) at which combustion ends. As one example, when the combustion end crank angle is approximately ATDC 80°, the crank angle $\theta_{PV_{max}}$ is ATDC 20 to 25°.

Although the maximum internal energy PV_{max} is the maximum amount of internal energy in a cylinder, in addition to internal energy generated by combustion, that value also includes internal energy that relates only to compression and expansion of in-cylinder gas carried out by the piston. Therefore, in the following processing, the PV value at the crank angle $\theta_{PV_{max}}$ at a time of non-combustion is acquired as a reference internal energy $PV0$. Since the PV value at a time of non-combustion depends only on the vertical movement of the piston, as shown by a hypothetical

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line in FIG. 9, the PV value changes symmetrically about top dead center (0°). By utilizing this characteristic, the reference internal energy $PV0$ at the crank angle $\theta_{PV_{max}}$ that cannot be obtained at a time of combustion can be acquired as a PV value at a crank angle $-\theta_{PV_{max}}$ that is symmetrical with the crank angle $\theta_{PV_{max}}$.

According to the present embodiment, the internal energy maximum change amount ΔPV_{max} as the first parameter is calculated by the following equation (6) based on a difference between the maximum internal energy PV_{max} and the reference internal energy $PV0$. Since the internal energy maximum change amount ΔPV_{max} calculated in this manner is the maximum amount of change in the internal energy that is changed by combustion, that is, a difference between the PV value at a time of combustion and the PV value at a time of non-combustion (difference in the internal energy), the internal energy maximum change amount ΔPV_{max} has a correlation with the indicated torque. Further, since the internal energy maximum change amount ΔPV_{max} includes an absolute value of the in-cylinder pressure P as it is, the internal energy maximum change amount ΔPV_{max} is a parameter that is affected by the output sensitivity of the in-cylinder pressure sensor.

$$\Delta PV_{max} = PV_{max} - PV0 \quad (6)$$

(Second Parameter)

The internal energy ratio ($\Delta PV_{max}/PV0$) that is the second parameter is calculated as a ratio of the maximum internal energy PV_{max} to the reference internal energy $PV0$. More specifically, according to the present embodiment, two indicators ΔPV_{max} and $PV0$ are calculated based on the in-cylinder pressure P and the like obtained at different crank angles $\theta_{PV_{max}}$ and $-\theta_{PV_{max}}$ in the same cycle, and the internal energy ratio ($\Delta PV_{max}/PV0$) is calculated based on the ratio between these indicators. Since the internal energy ratio ($\Delta PV_{max}/PV0$) obtained in this manner includes the in-cylinder pressure P in the denominator and the numerator thereof, respectively, the internal energy ratio ($\Delta PV_{max}/PV0$) is a parameter that is not affected by the output sensitivity of the in-cylinder pressure sensor.

(Sensitivity Abnormality Detection Processing)

Next, processing to detect a sensitivity abnormality is described referring to FIG. 10. FIG. 10 is a characteristics diagram that illustrates the relationship between the internal energy maximum change amount ΔPV_{max} and the internal energy ratio ($\Delta PV_{max}/PV0$). As will be understood from the definition thereof, the internal energy ratio ($\Delta PV_{max}/PV0$) has a proportionality relationship with the internal energy maximum change amount ΔPV_{max} . Therefore, processing to detect a sensitivity abnormality is performed in a similar manner to Embodiment 1 based on a determination coefficient α that is a ratio between the two values, and an allowable range (upper limit value α_{max} and lower limit value α_{min}) corresponding to the slope of a reference characteristic line L shown in FIG. 10. According to the present embodiment, the determination coefficient α is calculated by the following equation (7).

$$\alpha = \Delta PV_{max} / (\Delta PV_{max} / PV0) \quad (7)$$

[Specific Processing to Realize Embodiment 3]

Next, specific processing for implementing the above described control is described with reference to FIG. 11. FIG. 11 is a flowchart that illustrates control executed by the ECU according to Embodiment 3 of the present invention. It is assumed that the routine shown in FIG. 11 is repeatedly executed during operation of the engine. According to the routine shown in FIG. 11, first, in step 200, for example, the

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maximum internal energy PVmax is acquired by referring to time-series data of the PV value for one cycle that is stored in the ECU 50. Further, in step 202, the crank angle θ_{PVmax} at which the maximum internal energy PVmax is obtained is acquired, and in step 204, the crank angle $-\theta_{PVmax}$ that is symmetrical with the crank angle θ_{PVmax} about top dead center is acquired.

Next, in step 206, for example, by referring to time-series data, the ECU 50 acquires the reference internal energy PV0 based on the PV value at the crank angle $-\theta_{PVmax}$. Subsequently, in step 208, the ECU 50 calculates the internal energy maximum change amount $\Delta PVmax$ by the above described equation (6), and in step 210 the ECU 50 calculates the internal energy ratio ($\Delta PVmax/PV0$). Next, in step 212, the ECU 50 calculates the determination coefficient α by the above described equation (7), and in step 214, the ECU 50 determines whether or not the determination coefficient α falls within the allowable range. If the result determined in step 214 is affirmative, that is, if the expression $\alpha_{max} \geq \alpha \geq \alpha_{min}$ holds, in step 216 the ECU 50 determines that the output sensitivity of the in-cylinder pressure sensor is normal. In contrast, if the result determined in step 214 is negative, in step 218 the ECU 50 determines that the output sensitivity is abnormal.

According to present embodiment configured in this manner also, the same operational advantages as in the above described Embodiment 1 can be obtained, and a sensitivity abnormality of the in-cylinder pressure sensor 44 can be detected without depending on the operating condition of the engine. In particular, because the internal energy maximum change amount $\Delta PVmax$ is an amount of change in the internal energy that is generated by combustion, the internal energy maximum change amount $\Delta PVmax$ can absorb a variation in the heat release quantity that is produced by a change in the combustion center of gravity and the like. Thus, even if the combustion center of gravity changes, a sensitivity abnormality of the in-cylinder pressure sensor can be accurately detected.

In addition to the above described advantage, the following advantages can also be obtained according to the present embodiment. First, an output error (thermal strain error) that is caused by thermal strain of the sensor is liable to arise in the output of the in-cylinder pressure sensor 44. Thermal strain of the sensor mainly occurs in a diaphragm that covers a piezoelectric element, and arises due to the diaphragm deforming in accordance with a difference between thermal expansion amounts on a front surface side and a rear surface side. Therefore, occurrence of a thermal strain error tends to be noticeable from immediately after the end of combustion, due to a response delay or the like caused by conduction of heat to the diaphragm. In contrast, according to the present embodiment, since the internal energy maximum change amount $\Delta PVmax$ can be acquired at a crank angle θ_{PVmax} that is further to the spark advance side than the combustion end crank angle, the output sensitivity of the in-cylinder pressure sensor can be determined at a timing at which the internal energy maximum change amount $\Delta PVmax$ is less apt to be affected by a thermal strain error, and thus the accuracy of detecting a sensitivity abnormality can be enhanced.

Further, low-frequency noise that is produced by injection of fuel or seating of a fuel injection valve is liable to arise in a detection value of the in-cylinder pressure at the combustion end crank angle. This kind of low-frequency noise cannot be easily removed by a low-pass filter or the like, and causes an error to arise in the heat release quantity PV* or indicated torque A2 or the like. In this respect,

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according to the present embodiment, the influence of noise can be avoided for the above described reason. In addition, because the timing for acquiring the internal energy maximum change amount $\Delta PVmax$ is one at which the PV value is at a maximum and the in-cylinder pressure P is high, that is, a timing at which the resolution of an in-cylinder pressure waveform is high (the signal-to-noise ratio is favorable), a sensitivity abnormality can be detected more accurately.

Note that, in the above described Embodiment 3, steps 200 to 208 in FIG. 11 show a specific example of first parameter acquisition means according to claims 1 and 4, and step 210 shows a specific example of second parameter acquisition means. Further, steps 212, 214, 216, and 218 show a specific example of abnormality detection means. In addition, step 200 shows a specific example of maximum internal energy calculation means according to claim 4, and steps 202, 204, and 206 show a specific example of reference internal energy calculation means.

Embodiment 4

Next, Embodiment 4 of the present invention is described with reference to FIG. 12. A feature according to the present embodiment is that parameters used in the above described Embodiments 1 and 3 are combined. According to the present embodiment, components that are the same as in Embodiments 1 and 3 are denoted by the same reference symbols, and a description of such components is omitted. [Features of Embodiment 4]

FIG. 12 is a characteristics diagram that shows the relationship between the internal energy maximum change amount $\Delta PVmax$ and the indicated torque ratio ($A2/A1$) according to Embodiment 4 of the present invention. As shown in FIG. 12, according to the present embodiment, the internal energy maximum change amount $\Delta PVmax$ is acquired as a first parameter and the indicated torque ratio ($A2/A1$) is acquired as a second parameter. As described in the foregoing, the internal energy maximum change amount $\Delta PVmax$ has a correlation with the indicated torque, and hence a characteristic line L shown in FIG. 12 can be obtained.

According to the present embodiment, after acquiring the internal energy maximum change amount $\Delta PVmax$ and the indicated torque ratio ($A2/A1$) by the same method as in Embodiments 1 and 3, the determination coefficient α is calculated based on the following equation (8). Subsequently, processing to detect a sensitivity abnormality is performed in a similar manner to Embodiment 1 based on the calculated determination coefficient α and an allowable range (upper limit value α_{max} and lower limit value α_{min}) corresponding to the slope of the reference characteristic line L shown in FIG. 12.

$$\alpha = \Delta PVmax / (A2/A1) \quad (8)$$

According to the present embodiment configured in this manner also, the same operational advantages as in the foregoing Embodiment 3 can be obtained. Note that, as specific processing for implementing Embodiment 4, for example, relative to the processing of Embodiment 3 (FIG. 11), step 102 of the processing of Embodiment 1 (FIG. 6) is executed instead of step 210 in FIG. 11. Thereafter, in step 212, it is sufficient to calculate the determination coefficient α based on the above described equation (8).

Embodiment 5

Next, Embodiment 5 of the present invention is described with reference to FIG. 13 to FIG. 15. A feature according to the present embodiment is that parameters used as the first and second parameters are different to those used in the above described Embodiments 1, 3 and 4. In this connection,

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according to the present embodiment, components that are the same as in Embodiment 1 are denoted by the same reference symbols, and a description of such components is omitted.

[Features of Embodiment 5]

FIG. 13 is a characteristics diagram that shows the relationship between the maximum in-cylinder pressure Pmax and a specific combustion rate crank angle θ_{SMFB} according to Embodiment 5 of the present invention. As shown in FIG. 13, according to the present embodiment, the maximum in-cylinder pressure Pmax that is a maximum value of the in-cylinder pressure P during a single cycle is acquired as a first parameter. Further, as shown in equation (9) below, a specific combustion rate crank angle θ_{SMFB} that is a crank angle at which the mass fraction of burned fuel MFB matches a predetermined reference value SMFB is acquired as a second parameter. In this connection, the following equation (9) is derived from the above equation (2).

$$SMFB = \frac{PV^{\kappa}(\theta_{SMFB}) - PV^{\kappa}(\theta_e)}{PV^{\kappa}(\theta_s) - PV^{\kappa}(\theta_e)} \quad (9)$$

Thus, according to the present embodiment, two indicators $PV^{\kappa}(\theta_s)$ and $PV^{\kappa}(\theta_e)$ are calculated based on the in-cylinder pressure P and the like obtained at different crank angles θ_s and θ_e in the same cycle, and the specific combustion rate crank angle θ_{SMFB} is acquired based on a ratio between the indicators. More specifically, the reference value SMFB is a ratio between two indicators $\{PV^{\kappa}(\theta_s) - PV^{\kappa}(\theta_e)\}$ and $\{PV^{\kappa}(\theta_{SMFB}) - PV^{\kappa}(\theta_e)\}$ that are calculated based on the in-cylinder pressure P and the like at crank angles θ_s and θ_e , and the specific combustion rate crank angle θ_{SMFB} is acquired based on the reference value SMFB. In equation (9), the in-cylinder pressure P is included in the denominator and numerator, respectively, and hence the specific combustion rate crank angle θ_{SMFB} that is acquired based on the reference value SMFB is a parameter that is not affected by the output sensitivity of the in-cylinder pressure sensor.

The reference value SMFB is set to an arbitrary constant value within a range of 0 to 100%, and is previously stored in the ECU 50. FIG. 14 is an explanatory view that shows, for example, a specific combustion rate crank angle θ_{50} in a case where SMFB=50% in a characteristics diagram of the mass fraction of burned fuel. As shown in FIG. 14, the specific combustion rate crank angle θ_{SMFB} changes together with the characteristic line of the mass fraction of burned fuel in accordance with the combustion state. However, the relationship shown by the reference characteristic line L in FIG. 13 holds between the specific combustion rate crank angle θ_{SMFB} and the maximum in-cylinder pressure Pmax. Therefore, processing to detect a sensitivity abnormality is performed similarly to Embodiment 1 based on the determination coefficient α that is the ratio between the two values, and an allowable range (upper limit value α_{max} and lower limit value α_{min}) that corresponds to the slope of the reference characteristic line L. According to the present embodiment, the determination coefficient α is calculated by the following equation (10).

$$\alpha = P_{max} / \theta_{SMFB} \quad (10)$$

[Specific Processing to Realize Embodiment 5]

Next, specific processing for implementing the above described control is described with reference to FIG. 15.

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FIG. 15 is a flowchart that illustrates control executed by the ECU according to Embodiment 5 of the present invention. It is assumed that the routine shown in FIG. 15 is repeatedly executed during operation of the engine. According to the routine shown in FIG. 15, first, in step 300, the ECU 50 acquires the maximum in-cylinder pressure Pmax. Further, in step 302, the ECU 50 acquires the specific combustion rate crank angle θ_{SMFB} based on the above equation (9).

Next, in step 304, the ECU 50 calculates the determination coefficient α by the above equation (10), and in step 306 determines whether or not the determination coefficient α falls within the allowable range. If the result determined in step 306 is affirmative, that is, if the expression $\alpha_{max} \geq \alpha \geq \alpha_{min}$ holds, in step 308 the ECU 50 determines that the output sensitivity of the in-cylinder pressure sensor is normal. In contrast, if the result determined in step 306 is negative, in step 310 the ECU 50 determines that the output sensitivity is abnormal.

According to present embodiment configured in this manner also, the same operational advantages as in the above described Embodiment 1 can be obtained, and a sensitivity abnormality of the in-cylinder pressure sensor 44 can be detected without depending on the operating condition of the engine. The following advantages can also be obtained according to the present embodiment.

First, as shown in FIG. 14, the mass fraction of burned fuel MFB reaches 100% at a crank angle that is further to the spark advance side than the combustion end crank angle θ_e (approximately ATDC 80°). More specifically, at the time of calculating the MFB, the combustion end crank angle θ_e used in the above equation (9) can be set to a crank angle (for example, approximately ATDC 60°) that is further to the spark advance side than the actual combustion end point. According to this setting, the specific combustion rate crank angle θ_{SMFB} can be calculated at a timing that is further to the spark advance side than the actual combustion end point, that is, at a timing before a thermal strain error starts to occur. Further, since the maximum in-cylinder pressure Pmax similarly occurs at a timing that is further to the spark advance side than the actual combustion end point, it is difficult for the maximum in-cylinder pressure Pmax to be affected by a thermal strain error. Thus, according to the present embodiment, similarly to the above described Embodiment 3, the output sensitivity of the in-cylinder pressure sensor can be accurately detected.

Furthermore, according to the present embodiment, based on the specific combustion rate crank angle θ_{SMFB} at which the mass fraction of burned fuel MFB is a predetermined ratio (reference value SMFB), the determination coefficient α that is the ratio of the maximum in-cylinder pressure Pmax to the crank angle in question is calculated. Therefore, even if the combustion center of gravity is changed by ignition timing control or the like, the determination coefficient α is not affected by such a change. Thus, according to the present embodiment, the same advantages as in the above described Embodiment 2 can be obtained, and a sensitivity abnormality of the in-cylinder pressure sensor can be detected with high accuracy irrespective of a change in the combustion center of gravity.

Note that, in the above described Embodiment 5, step 300 in FIG. 15 shows a specific example of first parameter acquisition means according to claims 1 and 6, and step 302 shows a specific example of second parameter acquisition means. Further, steps 304, 306, 308, and 310 show a specific example of abnormality detection means. Also, the charac-

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teristics diagram shown in FIG. 14 and the above equation (9) constitute a specific example of MFB calculation means according to claim 6.

In Embodiments 1 to 5, a configuration is adopted in which the relationship between the first parameter and the second parameter is calculated as the determination coefficient α , and abnormality detection is performed based on the determination coefficient α . However, the present invention is not limited thereto, and for example, a configuration may be adopted in which the relationship between the first parameter and the second parameter is stored in advance as a data map that changes according to the operating conditions or the like, and abnormality detection is performed based on the data map. Thus, even when there is a correlation other than a proportionality relationship between the first parameter and the second parameter, abnormality detection can be executed based on the relationship between the two parameters.

DESCRIPTION OF REFERENCE NUMERALS

10 engine (internal combustion engine), 12 piston, 14 combustion chamber, 16 crankshaft, 18 intake passage, 20 exhaust passage, 22 throttle valve, 24 catalyst, 26 fuel injection valve, 28 spark plug, 30 intake valve, 32 exhaust valve, 40 crank angle sensor, 42 airflow sensor, 44 in-cylinder pressure sensor, 50 ECU, PV^* heat release quantity (first parameter), $A2/A1$ indicated torque ratio (second parameter), $A1, A2$ indicated torque (indicator), α determination coefficient (relationship between first and second parameters), α_{max} , α_{min} upper limit value, lower limit value of allowable range (criterion for determining), ΔPV_{max} internal energy maximum change amount (first parameter, indicator), $\Delta PV_{max}/PV0$ internal energy ratio (second parameter), $PV0$ reference internal energy (indicator), P_{max} maximum in-cylinder pressure (first parameter), θ_{SMFB} specific combustion rate crank angle (second parameters), $SMFB$ reference value, θ_s combustion start crank angle, θ_e combustion end crank angle

The invention claimed is:

1. A control apparatus for an internal combustion engine, comprising:

an in-cylinder pressure sensor configured to output a signal corresponding to an in-cylinder pressure of the internal combustion engine; and

an electronic control unit programmed to;

acquire a first parameter which is acquired based on the output of the in-cylinder pressure sensor and which is affected by an output sensitivity of the sensor;

acquire a second parameter which has a correlation with the first parameter and which is not affected by the output sensitivity, and calculate two indicators based on in-cylinder pressures obtained at different crank angles in an identical cycle and calculate the second parameter based on a ratio between the indicators;

determine whether or not an abnormality of the output sensitivity of the in-cylinder pressure sensor exists based on a relationship between the first parameter and the second parameter; and

control at least one of a throttle valve, a fuel injection valve, or a spark plug based upon a result of the abnormality determination.

2. The control apparatus for an internal combustion engine according to claim 1, where the electronic control unit is further programmed to:

by integrating multiplication values obtained by multiplying an amount of change in an in-cylinder volume

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per unit crank angle by an in-cylinder pressure in a predetermined crank angle range, calculate an indicated torque corresponding to the crank angle range;

wherein:

a heat release quantity PV^* that is calculated based on an in-cylinder pressure, an in-cylinder volume, and a ratio of specific heat is the first parameter; and

a ratio between an indicated torque $A1$ that is calculated in a crank angle range corresponding to a compression stroke and an indicated torque $A2$ that is calculated in a crank angle range corresponding to an expansion stroke is the second parameter.

3. The control apparatus for an internal combustion engine according to claim 2, wherein the electronic control unit is further programmed to:

set a determination criterion that a relationship between the first parameter and the second parameter should satisfy when the output sensitivity of the in-cylinder pressure sensor is normal; and

correct the determination criterion based on a deviation between a combustion center of gravity calculated in a cycle in which abnormality detection of the output sensitivity is performed and a reference combustion center of gravity that is previously set.

4. The control apparatus for an internal combustion engine according to claim 1, wherein the electronic control unit is further programmed to:

calculate a PV value by multiplying an in-cylinder pressure at an arbitrary crank angle by an in-cylinder volume at the crank angle, and acquire a maximum value of the PV value during one cycle as a maximum internal energy PV_{max} ; and

acquire a crank angle that is symmetrical about a top dead center position with a crank angle at which the maximum internal energy PV_{max} is obtained, and calculate the PV value at the crank angle as a reference internal energy $PV0$;

wherein:

an internal energy maximum change amount ΔPV_{max} that is obtained by subtracting the reference internal energy $PV0$ from the maximum internal energy PV_{max} is the first parameter; and

a ratio ($\Delta PV_{max}/PV0$) between the internal energy maximum change amount ΔPV_{max} and the reference internal energy $PV0$ is the second parameter.

5. The control apparatus for an internal combustion engine according to claim 1, wherein the electronic control unit is further programmed to:

by integrating multiplication values obtained by multiplying an amount of change in an in-cylinder volume per unit crank angle by an in-cylinder pressure in a predetermined crank angle range, calculate an indicated torque corresponding to the crank angle range;

calculate a PV value by multiplying an in-cylinder pressure at an arbitrary crank angle by an in-cylinder volume at the crank angle, and acquire a maximum value of the PV value during one cycle as a maximum internal energy PV_{max} ; and

acquire a crank angle that is symmetrical about a top dead center position with a crank angle at which the maximum internal energy PV_{max} is obtained, and calculate the PV value at the crank angle as a reference internal energy $PV0$;

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wherein:

an internal energy maximum change amount ΔPV_{max} that is obtained by subtracting the reference internal energy PV_0 from the maximum internal energy PV_{max} is the first parameter; and

a ratio ($A2/A1$) between an indicated torque $A1$ that is calculated in a crank angle range corresponding to a compression stroke and an indicated torque $A2$ that is calculated in a crank angle range corresponding to an expansion stroke is the second parameter.

6. The control apparatus for an internal combustion engine according to claim 1, wherein the electronic control unit is further programmed to:

calculate, a heat release quantity PV^k based on an in-cylinder pressure, an in-cylinder volume, and a ratio of specific heat, and calculate a mass fraction of burned fuel at an arbitrary crank angle based on a ratio between a heat release quantity PV^k (θ_s) at a combustion start crank angle θ_s and a heat release quantity PV^k (θ_e) at a combustion end crank angle θ_e ;

wherein:

a maximum in-cylinder pressure P_{max} during one cycle is the first parameter; and

a crank angle θ_{SMFB} at which the mass fraction of burned fuel matches a predetermined reference value $SMFB$ is the second parameter.

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